THE PHYSIOGRAPHY OF THE SHOALHAVEN RIVER VALLEY. VI.

Conclusion.

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(Five Text-figures.)

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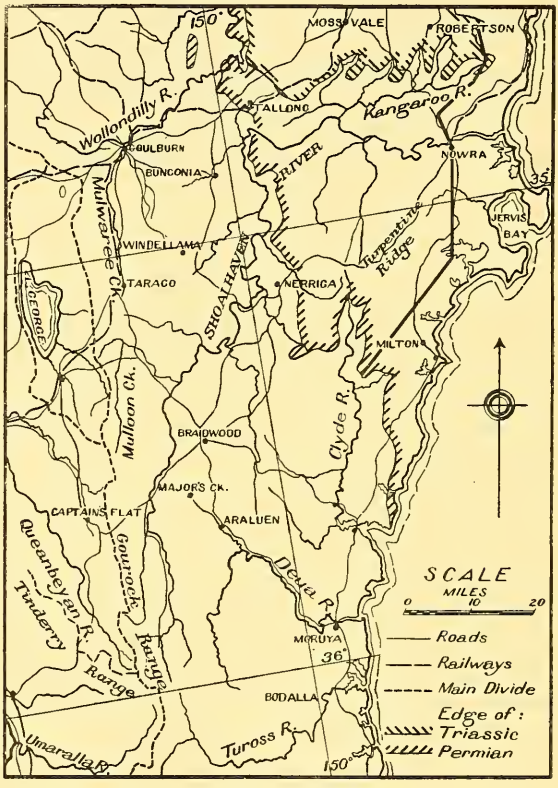
This paper may be regarded as a concluding part in the sense that it assembles and summarizes the principal results which have been obtained by a physiographic study of the Shoalhaven Valley, but it is also a prelude to wider considerations in beginning the application of those conclusions to the surrounding region. Among the ideas developed are some that may be used generally in the study of the eastern highlands of this State, such as the recognition of great terraces carved by the forces of normal erosion and leading up in steps towards the central plateau mass, as Andrews has described for New England, and the accidental direction of the present Main Divide, much of which has little physiographic significance in such areas as this. In addition, it appears that many coastal streams have been directed into depressions which occur at intervals along the flanks of the highlands, and the existing stream system is of great age, for the most part. A few parts of the coastal slopes (as distinct from the northward-falling Shoalhaven Valley) have been touched on, but the greater portion will be discussed by Dr. I. A. Brown, whose friendly criticism of this work has resulted in many improvements in its form.

Introduction.

The earlier papers of this series have provided a number of studies on the development of the various land forms and surfaces in the Shoalhaven Valley, so we are now in a position to generalize, and to extend our studies to the adjoining coastal slopes. The Shoalhaven basin includes the greater part of the vertical range of the New South Wales tablelands, as points within it rise to 4,800 feet and others immediately to the west are 500 feet higher, so it may be used to determine the growth and evolution of the southern highlands. Such a study is favoured by the disposition of the area, because its ancient features have been protected from the destructive influences of the steeper coastal streams, although erosional forms have been developed as the result of each significant earth movement. These forms provide a history which falls into three main stages: the first involved the formation and peneplanation of the Kanimbla (Hercynian) folds; the second ended with a surface of Triassic and Permian strata just above sea-level, and a southward rise in older rocks with wide valleys and incomplete peneplains cut down almost to the old level of deposition; the third witnessed a series of uplifts which brought the modern canyon cycle into being. Most of the existing surface has been above sea-level since the

Kanimbla folding, so the streams outside the Permian and Triassic areas may have a considerable age; nor is it remarkable that we should look for their beginning so far back in the past, as there has been an absence of great folding movements, while conditions of structure, elevation and, perhaps, of climate



Text-fig. 1.—Locality Map. Cambewarra Range is between the Kangaroo and Shoalhaven Rivers, and the heavy line indicates the section of Text-fig. 2. The arrow shows the magnetic meridian.

have limited their activities in changing their mutual relationships. It is better to regard the whole problem from the point of view of major events or cycles rather than from that of absolute time, because even the names of many of the usual chapters of geological history are missing from the region.

Morphology.

1. *The Older Surfaces.*—The eastern part of the Wollondilly basin (Craft, 1928) marches with the territory of the lower Shoalhaven, and is essentially a plain rising to 2,400 feet which has been dissected maturely to a depth of 400 feet. The undisturbed surface of the Triassic Wianamatta shale lies at 2,350 feet: much of it was covered by Tertiary basalts which also filled its gentle valleys, although these were later re-developed and amplified, and they extend past Tallong into the Shoalhaven area at a uniform altitude of 2,000 feet. The

Wianamatta shales were deposited in a syncline of Triassic Hawkesbury sandstones whose edges rise a little above the shales except to the west, where the passage to the differentially uplifted country across the Wollondilly sees their surface exceeding 2,500 feet. There is no evidence that sedimentation extended much above the present upper surface of the Wianamatta, and we may regard such high points as Twin Hill (2,360 feet) at Tallong as survivals of the old levels of deposition.

When the lower Shoalhaven is approached from the north, it is found that the Hawkesbury Series thins rapidly and gives place to the Upper Coal Measures on the tableland surface without any marked change of elevation, except as the result of comparatively recent dissection. The Coal Measures are also thin on the points approaching closest to the Shoalhaven, although they thicken rapidly northward; there is no record of the basal Triassic beds, the Narrabeen Series, on the western part of this southern margin, although they appear in Kangaroo Valley. Similar conditions to these are noticed on the western edge of the formations near the Wollondilly River, and the modern extent of the Triassic and Coal Measure rocks gives a fairly accurate definition of the south-western limits of the basin in which they were deposited, although in the Nowra district it extended to the south of the modern Shoalhaven.

The underlying Upper Marine Series shows the maximum extent of the Permian depression; its western and south-western edges cut out rapidly, and again the modern limits seem to be close to the original edge, except in the Clyde basin, where Lower Coal Measure strata occur in patches, and where the Upper Marine Series may have occupied the whole space between the existing coast and the Clyde. Against Currockbilly Range there are coarse shore-line deposits which extend to the north and north-west through Nerriga district and towards Tallong, and here the Corang-Shoalhaven stream line appears to have originated near their edge. At the head of Corang River these rocks form a tableland about 2,800 feet, and before denudation removed older rocks immediately to the west, the latter must have risen to a similar height and have continued southward, although their surface may have had a slight northerly dip in sympathy with that of the newer strata. We have noticed the great extent of this level about 3,000 feet on the divides (Craft, 1932) and in the middle and upper parts of the Shoalhaven Valley, and we also know that there was extensive peneplanation of the Kanimbla folds before the deposition of the Upper Marine Series: we can picture the present 3,000-foot level in the older rocks as the completion of this peneplain, and the similar but slightly lower surface of the Upper Marine Series as an extension built up in the shallow Permian sea, whose floor shelved gently from the shore line. That subsequent differential uplift to the south has been slight is shown by the sub-horizontal beds south of Major's Creek, whose upper surface continues the 3,000-foot level and rises in sympathy with the base of the series. There is no sign of extensive transverse faulting to indicate that these rocks have been dropped below their original position relative to those at the head of the Corang.

It might be objected that some definite allowance should be made for vertical denudation acting on the highest points of the landscape and that, despite the probable limitation of later sediments, they may have extended over much of the higher surface. In the first case, distinctively harder rocks stand out above the general level to form the residuals of Currockbilly and Budawang, and those of Bungonia district and of Goulburn, but the character and disposition of the

Upper Marine Series in this section are similar to those of the Upper Devonian beds south of Major's Creek, and it is unlikely that denudational losses would have changed their mutual relationship. Apart from this, the rock types and structures of the 3,000-foot level are very diverse, and any considerable lowering since their peneplanation would have resulted in a much greater diversity of elevations than is now observed. The second case presupposes surface developments of the nature we have outlined, but antedating any later deposition, and would only add another stage which would not invalidate our reasoning.

This (older) surface rises southward to 4,000 feet at the head of the Shoalhaven, but it has a great extent in the Tuross and Umaralla basins, as will be seen presently. In the greater part of the Shoalhaven Valley there is no definite surface above 3,400 feet, but that level extends through Gourock Range into the Molonglo basin, and northward along the western divide of the Shoalhaven, although it is not to be confused with the residual hills of the Bungonia and Goulburn districts which rise to a rather similar altitude, and of which some, at any rate, seem to have been monadnocks since Permian times. The loftier points of the ancient Gourock mass rise 1,400 feet above the old peneplain, and the peak of Tinderry Range is 500 feet higher than these. The development of the older peneplain marks the beginning of present-day topography.

The Newer Peneplain.—It is probable that the extension of the Upper Coal Measures to the south of the lower Shoalhaven was virtually confined to the Nowra district, so the area treated in the preceding section has been above sea-level since the Upper Marine period. The older peneplain in the Shoalhaven Valley has been maturely dissected in stages, and the newer features extend through narrow isoclinal ridges into the coastal slopes and the Murrumbidgee country. If the Shoalhaven Valley is considered in detail, the three divisions can be distinguished at 2,400 to 2,600 feet, 2,200 feet and 2,000 feet respectively. Of these, the last is the best standard of reference owing to the reduction of the other two near the main streams; in the sectional papers it has been referred to as the "Shoalhaven Plain", although it also has considerable development in the Wollondilly basin north of Tallong, and about Goulburn, Lake George and Queanbeyan (Sussmilch's "Yass-Canberra Plain"). It is horizontal as far south as the lower Mongarlowe, whence it sends branches up the main streams into the higher lands; its even surface is marked by the presence of late Tertiary drift.

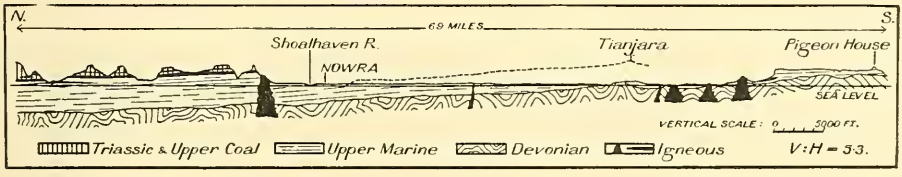
The highest of the divisions includes the upper surface of the Triassic rocks, together with the hills and higher plains along Mulwaree Creek and about Tarago, Reedy Creek and the Braidwood district, and the old levels in the high country west of Bungonia. These features rise from 2,350 feet in the north to 2,500 feet in the south, and 2,600 feet in the granite uplands near the western divide of the Shoalhaven. In the Nerriga district, residuals and old swampy valleys between 2,400 and 2,500 feet, and parts of Bulee Ridge, may belong to the same surface, and it extends up the Shoalhaven beyond the junction of Jinden Creek, where the sharper rise towards the head of the river coincides with splitting of the stream into its main sources.

So far as the intermediate stage is concerned, the peneplain at 2,200 feet in the Tallong district is well defined, and has some extension in the adjoining parts of the Wollondilly basin. Many hills in the Bungonia and Nerrimunga Creek districts rise to the same height, and further south there are terraces between the extreme levels of the first and third stages, including the plain divide of the Mongarlowe to the north-east of Braidwood (2,400 feet and less),

the divide at Major's Creek (2,300 feet), and the plains about Lake Bathurst (2,300 feet or less).

The interpretation of these features appears to be somewhat as follows: When the upper surface of the Triassic strata was near sea-level, the older peneplain rose gently southward and was dissected until a lower surface was formed which was co-extensive with the Triassic surface of deposition. Limited epeirogenic uplift caused this newer surface to be dissected to a depth of 200 feet, with the erosional forms produced dying out towards the sources of the main streams, and leaving much of the first stage intact. The uplift continued, and further denudation resulted in the formation of the Shoalhaven Plain during a long period of stability. It affected much the same area as the second stage, and the two combined with still more recent erosion to continue the reduction of the first, and to form hilly slopes where they rose to merge with it. Thus the undulating topography of the Braidwood district contrasts with the clear-cut definiteness of the various levels at Tarago, Nerriga and Tallong—a condition to which the prevailing granites also contributed. The coastal slopes consist largely of a dissected continuation of the newer peneplain, as an examination of their topography shows.

The Lower Shoalhaven.—The tributaries falling to the lower Shoalhaven from the south run northward parallel to the major joints of the rocks rather than along the line of greatest slope, which now trends towards the north-east. Part of their southern divide—Turpentine Ridge—has swampy levels between 1,600 and 1,700 feet, which overlook the coastal plain behind Jervis Bay, and lie below the height of Tianjara Trig. Station (2,517 feet): they bear the same relationship to that feature as the Shoalhaven Plain bears to Corang Trig. (Craft, 1931*d*), and their decreasing elevation and greater dissection towards the river are largely due to comparatively recent erosion. These levels stand back about the same distance from the coast as Cambewarra Range—13 miles—although that feature is rather higher, and brings the level tableland close to the lower Shoalhaven (Text-fig. 2). Although the entrenched part of the river extends downstream to Nowra, there is no great rise of the country for some miles up the



Text-fig. 2.—Section of the coastal plain and tableland in the Nowra district, after Jaquet and Harper. The 2,000-foot level is found on either side of the Shoalhaven River, and the broken line is added as an approximate profile of Turpentine Ridge to show the asymmetry of this part of the main valley.

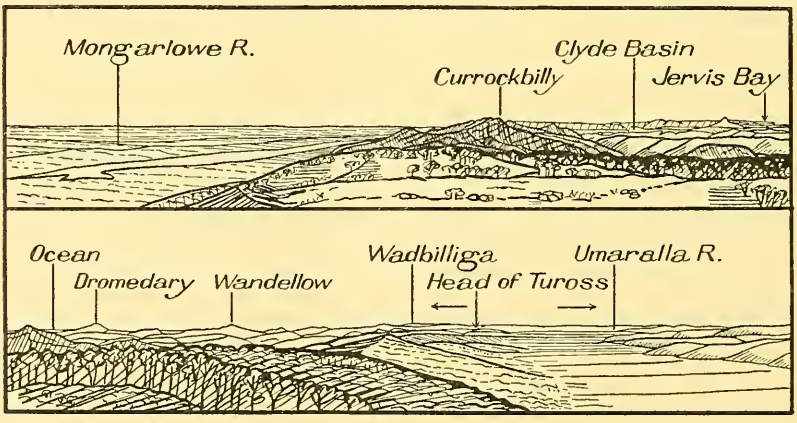
stream, which falls gently as it leaves the inclined plane. Away from the river, such heights as Nowra Hill rise to 600 feet, and they form a bench both here and to the south which has a steep seaward fall. Small streams and other forces of normal erosion have acted from the coast to cut limited flats and valleys, which extend a little further inland along the main rivers than elsewhere, and which form an irregular coastal plain. The Shoalhaven has also rebuilt the land surface which was reduced when sea-level was considerably

lower than it is now, although deep offshore water and strong currents inhibited delta formation.

There are two features near the mouth of the river that cause some confusion: the headlands enclosing Jervis Bay project beyond the general coastline and the exact reason for their existence is still unknown, while the other matter concerns the thinning of the Upper Coal Measures and the Upper Marine Series. With these rocks, the tendency was towards a series of deposition planes falling northward and being slightly concave: they are partly responsible for the asymmetric valley near the mouth of the river, as the fall from Turpentine Ridge is essentially a dip slope, while the rise to the north of the stream is an erosion scarp capped by the harder volcanics and Triassic strata. The asymmetry becomes less notable as the river is ascended, and the basal Upper Marine beds rise to form the tableland surface 10 miles to the east of the great bend at Tallong. The pauses between the initial stages of the last great series of uplifts allowed part of the erosion of softer rocks about Nowra, and the formation of the wide upper valleys and terraces which extend into the tableland along tributaries of Kangaroo River. That stream was probably initiated near the edge of the Triassic rocks owing to a slight local dip to the south-west.

In conclusion, it may be stated that the interaction of erosional forces and geological features has given the existing topography at the mouth of the Shoalhaven; that the horizontal tableland now about 2,000 feet originally extended to the south of the lower Shoalhaven, and that the first stages in the dissection of that surface produced the marginal terraces now found between 1,500 and 1,700 feet.

Clyde River (Text-figs. 2, 3).—The salient features of the Clyde Valley require only a brief description. Currockbilly and Budawang ridges fall sharply eastward to a peneplain cut in Devonian and early Palaeozoic strata, and showing a skyline of some regularity; the Upper Marine sandstones to the north stand as a high tableland above this surface, with Pigeon House (2,358 feet) as a detached residual of



Text-fig. 3.—Top: Topographical sketch looking northward from Mt. Budawang. This shows the Shoalhaven Plain on the left, the residual ridge of Currockbilly, the sandstone tableland in the right background, and the falling and dissected peneplain of the Clyde basin. Bottom: View southward along the Main Divide from Big Badja Hill, to show the warped peneplain falling to the coast from its level western extension in the Umaralla valley.

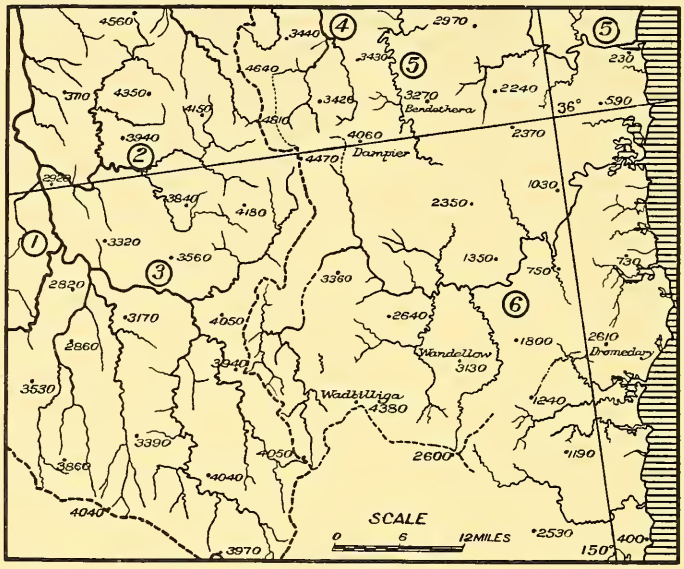
their falling surface. Against its western edge the peneplain has an elevation of 2,000 feet, and is a counterpart of the Shoalhaven Plain, the relationship between the two showing clearly when viewed from the residual ridges (Text-fig. 3). It falls steadily towards the south-east, as Jaquet and Harper (1915) have already noticed, and near the mouth of the Clyde its higher points are found between 700 and 900 feet. There is a correspondingly steep and concave fall from the head of Mongarlowe River, so we find the Clyde and its principal western tributaries—Currowan and Buckenbowra Creeks—flowing down the prevailing slopes to enter the sea where the peneplain surface has been considerably depressed.

The pattern of the Clyde system is imperfectly shown on existing maps. The peneplain surface is considerably below the northern and western divides, so the present streams have preserved their mutual relationships over a long period of time—since far back in the Tertiary period, at any rate. The Clyde is the key stream, and may have developed along the western edge of the Upper Marine Series; it is parallel to the major joints of those rocks and to the general strike of the underlying folded strata, so there has been no lack of definite lines of weakness to help preserve its meridional course, on which the effects of the peneplain stage are still visible in the form of meanders that are now entrenched in the old surface. The unmapped tributaries from Currockbilly and Budawang run eastward, but there is one anomaly in the course of a stream which flows east of north for some 10 miles to join the Clyde against the general direction of that river; it appears to be a subsequent developed along a granite intrusion. The parallel courses of Araluen Creek, the upper parts of Currowan and Buckenbowra Creeks, and a portion of the Deua River appear to be developed along parallel regional lines of weakness which may be seen both in the granites and the sedimentary rocks.

Deua and Tuross Rivers (Text-figs. 3, 4).—Conditions over much of the Deua basin are not essentially different from those existing over the Clyde, but the upper Deua can be classed with the upper Shoalhaven as regards origin and development (Craft, 1932). The older peneplain is preserved on the eastern side of the meridional section in a series of high ridges which rise above 3,000 feet, and the stream line follows the strike of the upper Devonian rocks, and has possibly been influenced by parallel fault lines (I. Brown, 1930). The head of the river is in rough country, and the divide looks to be 2,500 or 2,600 feet above sea-level; it is much below Mt. Dampier and the Bendethera ridge, so there is a wide opening in the uplands between the Deua and Tuross Rivers. Canyons of the present cycle extend to this divide, but the Deua has a remarkably meandering course throughout its length, many of the great bends apparently being inherited from the newer peneplain stage. That feature slopes eastward towards the mouth of the Deua from the Bendethera ridge.

The Tuross heads in a part of the Main Divide whose high points rise above 4,000 feet (Text-fig. 4), but its first course is northward over an undulating granite plain whose general level is 3,200 to 3,400 feet—an extension of the older peneplain: the river turns eastward across this level, and falls into a gorge that characterizes much of its length, although there is a shallowing as the newer peneplain falls towards the coast. We have noted a tributary—Woila Creek—as rising in the same swamps as the Shoalhaven at an altitude of 2,900 feet (Craft, 1932), with much higher country on either side, so the whole western section of the Tuross drainage is associated with the older peneplain, which extends westward without a break into the Umaralla basin. Relics of a still higher level

continue southward from Mt. Dampier (4,060 feet) to fall steeply to the gorges, while a similar fate overtakes the southern Tuross ridges about Wadbilliga Trig. (4,380 feet). It will be noticed that the upper Tuross is associated with the highest features developed as a regular level in the region, and there is an



Text-fig. 4.—Map to show the relationship of the Tuross and Umaralla Rivers, and the high points in their basins. The main streams are numbered: 1, Murrumbidgee; 2, Bredbo; 3, Umaralla; 4, Shoalhaven; 5, Deua; 6, Tuross.

analogy between it and the Umaralla, upon both of which similar patterns have been imposed by rock structure. Their efficiency in working is shown by the even skylines of the various higher levels near, and to the west of, the Main Divide, and they contrast with the parallel streams of the upper Shoalhaven and Murrumbidgee, which were unable to reduce the highest elements of the most ancient landscape, as the high points of Gourock and Tinderry show. With the Umaralla and upper Tuross the rock character is less resistant and more uniform, and generally the violent contrast between alternating hard and soft zones is missing: the presence of that contrast rather than the inherent resistance of the most obdurate rocks has greatly hindered complete peneplanation in the other areas, and has made the development of symmetrical stream systems almost impossible.

The Coastal Slopes.—To appreciate the significance of the coastal slopes it is necesssary to take a broad view of the littoral. The position of Robertson is of great importance: basalt flows have built up the surface of the tableland in its vicinity by 400 feet, and a gentle slope to the north leads to a sharper fall towards Sydney. A similar feature appears southward, where a gentle fall gives place to a steeper slope into the Clyde valley and the hollow to which the Clyde, Deua and Tuross Rivers flow. The essentials of the position were noted by Harper (1905 and 1915), who saw a definite connection between the crest of the

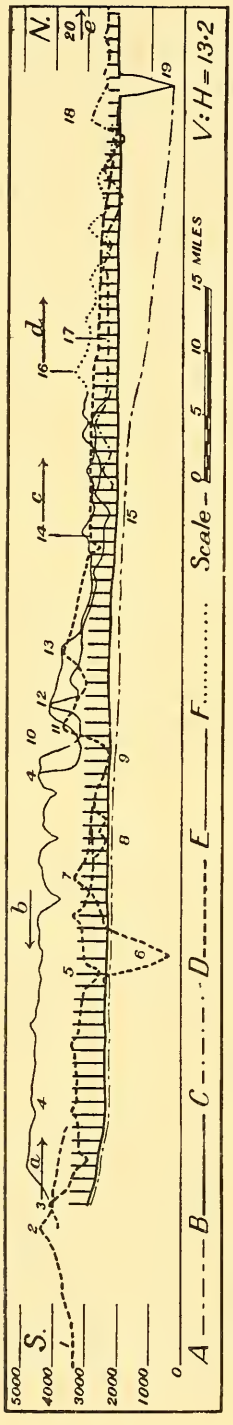
gentle arch and the Robertson basalts, and a similar explanation might be found for the Sassafras and Endrick valley flows, which occur where the slope changes from the unwarped tableland to the coastal depression, which is the great feature of the Clyde valley, on whose eastern side the newer peneplain has been cut off some 800 feet above sea-level in the erosion of the coastal plain. Late Tertiary basalts and sediments have been described between Jervis Bay and the mouth of the Tuross in places where more recent elevation has raised them by the order of 200 feet (I. A. Brown, 1925, 1928), and although their age has not been definitely established, it is generally believed that volcanic activity in this region did not extend into the Pleistocene. Thus it is necessary to place the essentials of the present coastal topography in the late Tertiary period, and to impose a similar upward limit on the process of tableland formation. The extension of the coastal plain since the latest basaltic period is not great, even in the country close to the lower Shoalhaven, so the process must be slow, and recent change has been almost confined to the enlargement of the canyons which furrow the coastal slopes. The older peneplain stands well back from the coastline, and does not attain any continuity until the eastern divide of the upper Deua and the headwater country of the Tuross are reached: very few residuals are found to the east of that locality, almost the whole expanse of the ancient surfaces having been reduced in the formation of the newer peneplain.

The depression we have noted in the Clyde valley developed in its present form before the erosion of the coastal plain; it is a counterpart of the Sydney basin, although on a less impressive scale, and it involves a relative lowering of 1,200 feet near the mouth of the Clyde. That river has maintained its course through a long period of time, so it was probably directed originally by a southward fall which was maintained during the newer peneplanation, and which was accentuated by warping during the main plateau uplift to give the existing bending and depression of the littoral.

History of the Land Surface.

The various surfaces or physiographic horizons developed in the Shoalhaven valley may thus be regarded as regional features; they are classified according to field continuity, and although each individual may occur extensively within narrow vertical limits, the bending or warping incidental to the various movements of elevation has served to disturb the original contour as one passes from east to west. Along meridional lines, much of the change in altitude can be ascribed to more ancient movements so far as the upper levels are concerned, and to erosional processes in the lower. The essential features of the valley may be summarized in a diagram (Text-fig. 5).

There is no doubt that the most notable peneplanation which has influenced or determined existing features was that preceding the deposition of the Permian rocks, because it eliminated the fold topography. The upper surface of the Upper Marine Series was co-extensive with its most highly developed phase, such hills as Currockbilly, Budawang, and those west of Bungonia being residuals even when Permian deposition was taking place, and there is no evidence of notable cross-faulting or sharp bending as one goes from north to south along the divides. On the contrary, the almost undisturbed upper Devonian rocks forming the eastern divide of the upper Shoalhaven have an erosion surface rising somewhat above that of the Upper Marine Series, so it would appear that our "older peneplain" is little removed from the surface which existed immediately after the



deposition of the Permian rocks, and the more complete peneplanation of old highlands which must have proceeded during that period. The older peneplain was preceded to the south by a still higher level about 4,000 or 4,500 feet (modern) which was the most complete regional feature developed, and which may have been the original master peneplain formed by the reduction of the Kanimbla and earlier folds, although not much of it now survives in this area.

Coming towards more recent times, the restriction of the Upper Coal Measures and of the Triassic basin point to elevation around their margins coincidentally with the depression of areas in which sediments were being deposited. The southward rise of the older peneplain may be ascribed to this cause: it certainly antedates the three stages of the newer peneplain, which sends its horizontal surfaces into the inclined mass. The first stage of the newer feature was eroded to be co-extensive with the final surface of deposition of the Triassic rocks; the second followed limited uplift, as did the most recent, the Shoalhaven Plain, which was so perfected over limited areas that, towards the latter part of the Tertiary period, considerable areas of it were covered with stream drift. Since that time the amount of change has been small except in the areas affected by the more recent uplifts of the Kosciusko period, where revived streams have cut deep gorges. The place of the coastal slopes in this scheme is clear from preceding sections: the principal surface represented is the combined Triassic upper level and the newer peneplain, the latter being warped down

Text-fig. 5.—Profiles to show the physiographic development of the Shoalhaven Valley. The principal features are parallel to the magnetic meridian, so all are projected on to that line, hence the occasional passage from ridges to valley profiles. The capital letters stand for: A.—Shoalhaven River; B.—newer peneplain, taking the best-developed lower level in each district; C.—ridges west of Bungonia; D.—discontinuous profiles of various sections of the eastern divide, and the Main Divide in the extreme south; E.—Gourock Range and its two northerly extensions, of which the upper leads to F, the ridge extending west of Mulwaree Creek. The arrows indicate the direction of various features extending from their bases; *a.*—sub-horizontal beds of the upper Devonian (to 8); *b.*—mature valleys replacing the newer peneplain; *c.*—Upper Marine Series; *d.*—northerly residuals of upper Devonian quartzite, above 2,500 feet; *e.*—Triassic rocks. Numbers stand for: 1.—Tuross-Umaralla divide; 2.—Big Badja Hill; 3.—Mt. Dampier; 4.—Gourock Range; 5.—Moodong gap; 6.—valley of Deua at the junction with Araluen Creek; 7.—Milo Trig.; 8.—gap at Major's Creek (side on); 9.—gap at Currowan Creek; 10.—lowered divides of Mulloon Creek; 11 and 13.—Mts. Budawang and Currockbilly, quartzite residuals; 12.—Palerang Peak; 14.—head of Corang River; 15.—Reedy Creek; 16.—Mt. Allianoyonyiga (Tarago); 17.—plain of Lake Bathurst; 18.—Vessey Trig.; 19.—Shoalhaven River, Tallong; 20.—Tallong. Note the favourable conditions for stream capture between 5 and 9. Vertical shading represents the denudation involved in the erosion of the newer peneplain, and for simplicity only a few points or profiles are shown for each surface; the sectional papers should be consulted for further details.

southward, and considerably dissected in the production of gorges and of a limited coastal plain. Although timing has been based on the conventional geological periods of sedimentation, it is clear that no rigid definitions are possible in this case, and they would not be desirable under any circumstances if they were taken to imply that each of the later sedimentary periods must be represented by some forms in an ancient landscape, or that a cycle of erosion fitted into one period. There is an obvious connection between mountain building, erosion, and sedimentation, but there is no reason why landscape development should not progress through several periods of extraneous sedimentation, especially when the surface concerned has the form of a low tableland in an area of great temporary stability, and field evidence in such an area as the Shoalhaven Valley shows that land forms may survive from period to period with comparatively little change provided that the rock types are sufficiently resistant, and the streams sufficiently incompetent.

The Stream Systems.

The development of the Deua and upper Shoalhaven Rivers has already been discussed, and some of the points raised by the question of stream capture have been considered (Craft, 1932), so this section can be devoted to a general review of the Shoalhaven and neighbouring streams. When the Kanimbla folding influenced this part of the State its trends were roughly parallel to the existing coast (I. Brown, 1931), thus favouring the existence and the further development of meridional streams—a tendency that would be continued by reason of the subsequent Permian depression to the north-east, and which would lead us to infer that the present transverse or oblique courses of certain coastal streams across this folded belt have developed since the reduction of the folds, and since the inception of the Permian depression. On the other hand, such streams as the upper courses of the Shoalhaven and Deua, and the meridional section of the Murrumbidgee north of Cooma appear to be the lineal successors of the original drainage lines.

To the south and south-west of the Shoalhaven, the oldest surface, now somewhat above 4,000 feet, appears to have had a slight northward fall, since there is evidence that the northward trending Umaralla is of great age. That stream has cut the older peneplain (3,000 to 3,400 feet) as a plain in the higher level, the slopes between the two being definite facets, and the peneplain falls slightly and gradually along the modern direction of flow of the Umaralla in much the same way as the corresponding surface in the Shoalhaven Valley falls northward. The Umaralla-Murrumbidgee line passes the isolated mass of Gourock and Tinderry in a comparatively narrow valley in which the older peneplain has been considerably dissected, although its level may be picked up again in the residuals which rise above the Canberra plain. In other words, the Umaralla maintained a course during the older peneplanation like that followed at present, and thus appears to have been inherited from the old surface now found in a rather fragmentary condition about 4,000 feet.

How, then, must the Tuross be regarded? Its similarity to the Umaralla leads to the belief that it was developed under similar conditions as regards the headwaters, at least, because they still flow in gentle valleys above 3,000 feet, although the parts nearer the coast may be considerably more modern. Considering the disposition of hills and ridge crests rising above 4,000 feet, it would appear that the ancient surface which they represent extended over the upper Tuross and Shoalhaven country as well as over the adjacent Umaralla-Murrumbidgee

region, in which case the northward fall deduced for the latter area may well have applied to the Tuross drainage. The originals of that stream would thus have fallen northward; in fact, the nature of the Kanimbla folds made a primitive meridional course inevitable in the relatively unfolded strip between the head of the Tuross, Mt. Dampier and Major's Creek, as in the gently folded country towards the coast.

But there were reasons why such a course should not persist. When the folds had been peneplaned and the resultant surface raised above sea-level, the inevitable eastward fall to the then-existing coast would cause streams to cut back from that direction along lines of weakness, assuming that they had not done so before, and attack the old meridional drainage, as in the later case of the Deua, setting up courses with a more direct passage to the sea.

Turning now to the Umaralla-Murrumbidgee stream line, we find that it was favourably situated for its own preservation, since it was able to exploit a persistent meridional line of weakness to the east of the Federal Territory granites, but no such line extended through the Tuross-Shoalhaven area. The Shoalhaven itself follows the western edge of the Upper Devonian rocks, a line of low resistance that is almost eliminated near the present head of the river by the convergence of the hard mass of southern Gourock, thus making the survival of any southern extension of the upper Shoalhaven a difficult matter. Altogether, there was a tendency for stream systems to develop about the head of the Shoalhaven at the expense of primitive drainages: of these newcomers, the Umaralla still discharged northward, but the Tuross developed more or less directly from the coast. Doubtless many of the original meridional valleys established along special lines of weakness have been exploited by later streams, but it would be extravagant to suppose that the original pattern could be reconstructed in detail from existing evidences.

In addition to the meridional and transverse streams there are others, such as a large part of the lower Deua, which pursue oblique courses along general lines of weakness. Professor David (1914) mentioned NNW-SSE trends (geographical meridian) in the northern edge of the Bathurst-Monaro tableland, and similar features have been recorded in the igneous rocks of the South Coast (I. Brown, 1928) and in the Ettrema gorges, to the north-east of Nerriga (Jensen, 1908). The present writer has noticed them in the Devonian and older rocks on either side of the Shoalhaven Valley, and in the associated granites, and it appears that attack along such lines, or along combined meridional and transverse features with a resultant trend in that direction, has resulted in the capture of certain meridional streams, such as Mulloon Creek and the upper Deua (Craft, 1932). This attack is still proceeding, so that the Shoalhaven above the vicinity of Major's Creek is threatened with capture and diversion to the Deua River. Oblique streams (NNW-SSE to NW-SE) thus form a definite family that is developing at the present day.

Coming now to the lower course of the Shoalhaven, it is found that the section immediately south of the great bend at Tallong lies immediately to the west of the Upper Marine Series, suggesting that it formed near that periphery. Where the river turns eastward there is a wide upland valley at 2,000 feet (Craft, 1931c), and a slight seaward fall is shown in the tableland on either side of the river. It is possible that the original Shoalhaven fell to the Triassic lake, as Taylor seems to suggest (1906), and when rocks of that age were finally raised

above sea-level, its new lower course became established off the edge of the resistant Hawkesbury Series to follow a short slope to the ocean. Recent stream changes in this district are of a minor character (Craft, 1931*a*).

Summing up this aspect, the principal stream families of the region are found to be three in number, namely:

1. The Meridional, which developed along the slopes and may have originated along the Kanimbla folds, in some cases, and which fitted themselves to parallel structures. Examples are the upper Shoalhaven, the Mongarlowe and upper Deua Rivers, Mulwaree, Mulloon, and Butmaroo Creeks, and certain of the Murrumbidgee streams.

2. The Transverse and Oblique, which exploited joints and other lines of weakness, pushing back along later slopes at the expense of the older meridional streams. Examples are the lower courses of the Tuross and Deua Rivers, Reedy, Boro, Araluen, Currowan and Buckenbowra Creeks, all of which are subsequents.

3. Streams which developed off the edges of horizontal formations when the latter were raised above sea-level. This type includes the head and lower course of the Shoalhaven, much of the Wollondilly and part of Clyde River, although the latter is rather doubtful.

A fourth type—that formed to drain the peripheral depressions of the tableland—is not represented here. Those portions of the Hawkesbury and Clarence in Mesozoic areas are examples.

These ideas have certain incidental consequences. The primary divides were aligned east and west, and the present Main Divide is a more or less haphazard line separating the streams which finally discharged eastward under the combined influence of the Permo-Triassic depression and the modern coast from those which eventually fell westward into depressions on that side. Thus the parallelism of the Main Divide and streams on either side of it is to be expected, because the streams have followed old meridional slopes and lines of weakness over long periods of time, the watershed consists of some of the resistant or stable features thus disclosed, and few streams exist to cause its migration as the result of direct headward attack. In conclusion of this section, it is recognized that the disposition of the present streams has controlled the development of the newer (mainly Tertiary) peneplain, and it also corresponds generally with the gentle slopes of the older peneplain, whose sections are partly separated from one another by exceptionally high masses, and which were carved out of a rather higher master surface. It is clear that the streams had attained their present development well before the end of the Tertiary period; those in the older surfaces may have been little changed since Triassic times, and their ultimate origin is associated with the Kanimbla folding. Alteration by capture and the development of the newer transverse and oblique lines is most notable on the coastal margin.

General Physiography.

These studies involve the consideration of certain problems of surface development which present themselves in a sequence; such as the horizons on which Tertiary basalts occur, the relationship of peneplanation to the Southern Tableland, and the tectonic significance of that feature, although the succeeding pages can only be a brief introduction to the matters involved, which may be taken in order.

The Horizons of the Tertiary Basalts.

The general age of the basalts occurring on the New South Wales tableland has been referred to by Walcott (1920) as upper Miocene or lower Pliocene, but a considerable vertical range is indicated by the various occurrences in or near the Shoalhaven Valley. Thus the Robertson group is spread over a plain surface and has filled the gentle valleys eroded therein, and these latter were subsequently re-developed and enlarged at a level now found at 2,000 feet: under the circumstances, the general age quoted is satisfactory, as it allows time for the considerable amount of weathering and erosion involved. The occurrences near Tallong are less simple, because the higher basalt appears to have flowed down to the 2,000-foot plain after that feature had virtually attained its present stage of development, and the nearby valley at Caoura, cut below that level, was filled with lava before the inception of the modern canyons. The flows, sediments and bauxites of the higher level occupy a plain which ends in an abrupt valley side and overlooks the lower flow. Further south there is the pre-canyon basalt of the Endrick valley, with a lower limit of 1,680 feet, thus disclosing a mean range of 670 feet between its base and that of the Robertson flows, with no appreciable warping or faulting between them.

Turning to the coastal basalts and sediments between Nowra and the mouth of Tuross River, they are found to lie on the coastal plain (I. Brown, 1925, 1928), and to post-date the commencement of canyon formation, as the surface in which that plain is eroded rises even higher to the north and west, as we have already seen. Such a position of occurrence contrasts with that of the Robertson basalts, whose outlying members to the west-north-west occur on the tableland above the deep and moderately old terraced canyon of the Wollondilly, which they antedate. Harper (1915) believed that certain intrusions into the coal seams of the Illawarra district were of Pleistocene age, as they post-dated faults in the coal measures referable to the last great uplift: on similar grounds he also ascribed a like age to the Robertson basalts, but his case is hardly convincing. At any rate, it seems that the basalts may have a considerable time range, those of the Illawarra district and of the South Coast being younger than the pre-canyon flows of the tableland. It is hardly possible to separate these latter, as there is evidence of volcanic action during the accumulation of the Shoalhaven drifts between 1,650 and 2,100 feet (Craft, 1931*d*), and the higher basalts at Tallong apparently extended down from 2,200 feet to the Shoalhaven Plain at 2,000 feet (modern heights). Nor is it possible to say from physiographic evidence that the Robertson flows are earlier than these, because the Shoalhaven channels that were filled with drift and basalt may well have been eroded below the Shoalhaven Plain without the Robertson area being affected by such features, seeing that downward erosion there has been limited even to the present day. The amount of erosion which the various flows have suffered is also no criterion of age, as those are best preserved which occur in remote valleys, while the basalts in higher areas have either had wide valleys cut in them by the combined action of weathering or gentle streams, or they have been removed so completely that the only evidence of their former extent is in the presence of contact quartzite ("grey billy"), or isolated masses of bauxite.

It seems that Pleistocene uplift was limited to the order of 200 or 300 feet disclosed by the raised sediments and basalts of the South Coast (I. Brown, 1928), and that period has been spent in the excavation of the canyons. (There have also been oscillations of sea-level that scarcely affect the present considera-

tions.) The considerable age thus inferred for the highly developed plains and valleys of the tablelands agrees well with the general tenor of our observations: the youthful-looking valley of the Endrick above Nerriga has changed little since the period of basalts (Craft, 1931*d*), while two of the head streams of the Shoalhaven—Point and Jerrabatgully Creeks—flow in steep-sided, narrow valleys in close proximity to the wide valleys and plains of the river. This is a case in which the familiar terms "juvenile" and "mature" lose their accustomed significance if used to describe relative valley ages on the basis of cross-sections.

Peneplanation and the Southern Tableland.

The conception of the whole Southern Tableland is largely determined by the foregoing considerations. At the close of the Palaeozoic era, the whole region had been peneplaned, although resistant features and structures mainly due to differential movement and faulting during the period of granitic intrusions rose to some height above the common level. It seems that further uplift supervened during the Mesozoic era, but there were no more great foldings, and the whole course of the more recent movements had been to produce a surface which has a broad, flat arch in section. The greatest uplift has been along a meridional line about the heads of the Snowy and Murrumbidgee Rivers, and the effect has been rather similar to that produced by inserting the blade of a knife under a cloth lying on a table, and lifting it gently. It is not surprising to find the elevation increasing towards the centre of the mass, because reduction would tend to be least complete there, and older positive movements must also have been greater away from the margins, seeing that these were first acted upon by forces of depression, and later the weight of a considerable body of newer sediments had to be overcome before there could be notable uplift on the periphery of the central mass. Viewed broadly, the south-eastern highlands of Australia were built of Palaeozoic rocks and formed a nucleus around which the present area of dry land tended to grow as forces of uplift became more widespread, and the Mesozoic and Tertiary rocks were lifted gently above sea-level.

As a result of the intermittent rising, there has been a continual attack on the upraised mass from the direction of its margins, and a number of incomplete peneplains have been formed of gradually decreasing extent, so that the most recent have a smaller area than that occupied by the oldest in respect to the pre-existing land mass, and the whole region falls into a series of terraces narrowing and rising towards a centre, where the oldest are still preserved at relatively high altitudes. The major terraces tend to be spaced at vertical intervals of 1,000 feet each, and in many localities they are separated from one another by steeper slopes or facets, especially towards the heads of the main rivers. The peripheral areas have been most reduced by the erosion of the more recent features, and the process has been revived by late Tertiary uplifts, which have caused the formation of limited coastal plains and the inception of a new terrace near sea-level, which is extending inland along the gorges.

This conception of the growth of the tableland gives an insight into the evolution of the stream system, whose distinctively modern form can be traced back to the cycle of erosion which reduced the Kanimbla folds and set up the main streams along meridional lines. As a result of the later uplifts there was a definite tendency towards a radial system diverging from the Kosciusko-Monaro highlands, with meridional elongations parallel to the reduced folds, and falling down the slopes to tectonic depressions. Transverse and oblique streams

developed on the flanks of the rising mass as newer streams took advantage of easterly or westerly components in the slope, and attacked along parallel lines of weakness, finally capturing or destroying parts of the original drainage pattern. Complications have been introduced by selective erosion in specially favourable zones, as on the southern edge of the Federal Territory granites in the headwater country of the Murrumbidgee, but even streams developed by such an action are of considerable age, going at least far back into the Tertiary period, and they do not hide the essential character of the whole pattern.

The Manner of Uplift.

Reference has been made to the flat cross-section of the highlands in the vicinity of the Shoalhaven Valley; perhaps this is better appreciated when it is realized that the coastal slope of the tilted newer peneplain is of the order of 1° 30′, while a line from Wadbilliga Trig. (4,380 feet, on the oldest surface, above the older peneplain) to the modern coast line makes an angle of less than 2° with the horizontal. Such values represent the effect of widespread warping, and it is difficult to see how such an action could be brought about by purely compressive forces in the earth's crust, or how such forces could have acted without giving considerable marginal folding or faulting, of which there is no evidence in surface features, or in the post-Devonian rocks of the region we have studied. At the same time, the absence of notable tensional forces is evidenced by a corresponding absence of rifts and normal faults both here and to the north, and uplift has been due to vertical movements and readjustments.

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